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Method and Psychological Effects on Learning Behaviors and Knowledge Creation in Quality Improvement Projects

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This study investigates two mechanisms of knowledge creation—one that is method driven and the other that is psychologically driven. Results show that the two mechanisms have different effects on the learning behaviors and knowledge created in Six Sigma projects. The method mechanism directly influences learning behaviors, while the psychological mechanism directly affects knowledge creation. The effects of both mechanisms on knowledge creation are complementary, yet independent. Findings suggest that the value of adhering to a method may lie in modifying the learning behaviors that subsequently create knowledge. When a firm adopts a quality program such as Six Sigma, the method and the degree of its adherence can shape how the firm innovates and creates knowledge.

Key words: knowledge management; organizational learning; quality improvement projects; Six Sigma
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1. Introduction

Where constant changes and high uncertainties are the norm, a learning orientation toward quality improvement becomes critical to sustained organizational performance (Sitkin et al. 1994). Learning and knowledge creation are related. Prior studies have investigated learning in quality, but most have inferred knowledge from some forms of learning (e.g. Lapré and Van Wassenhove 2001, Mukherjee et al. 1998). There is limited study on the direct impact on knowledge itself. In the knowledge-based view of the firm, knowledge represents a strategic resource that the firm uses to develop sustained competitive advantage (Kogut and Zander 1992). In this study, knowledge is defined as new ideas, improved understanding, and the capability of a team doing a quality project. To better capture how knowledge is generated, we differentiate knowledge from learning. We study learning as behaviors that involve information seeking, discussions, and asking questions. Therefore, learning behaviors can be viewed as a process variable and knowledge created as an outcome measure. Given the cognitive nature of knowledge creation and learning, we investigate two cognition-influencing mechanisms—method-driven and psychologically driven—and their influence on organizational members' cognitive processes to learn in a quality improvement setting. The method mechanism represents a structured and technical approach, and the psychological mechanism an unstructured and social approach, to knowledge creation and learning. While it is possible that a strong adherence to a method such as Six Sigma could stifle learning behaviors and hinder improvement efforts, it is also possible that the psychological effects could dominate the method effects because of human biases against following a method (Boiral 2003). The relative importance of the method and psychological effects on learning behaviors and knowledge creation, however, has not been directly examined in prior literature.

This research found that the method mechanism and psychological mechanism exhibit different and independent effects on learning behaviors and knowledge creation. The method mechanism influences learning behaviors, while the psychological mechanism affects knowledge directly. This finding suggests that the value of adhering to a method in quality improvement settings, such as Six Sigma, may lie in modifying the learning behaviors, which combines well with the effect of the psychological mechanism on knowledge creation. Such combined effects can

alter the learning path of a firm and have an impact on the effectiveness and sustainability of a quality program. This study uses Six Sigma as an example, but the theory is not based entirely on Six Sigma.

2. Theoretical Development

Among some researchers, quality management is viewed as problem solving: "Quality management is the quest for improvement in organizational routines through the application of a particular collection of problem-solving heuristics and techniques" (Winter 1994, p. 93). The use of the scientific method is a distinctive feature in quality improvement that represents an important source of learning (Hackman and Wageman 1995). It is associated with conceptual learning and the creation of know-why in quality improvement projects (Mukherjee et al. 1998). Besides the scientific method, problem-solving heuristics—such as the flow chart and cause-and-effect diagram—help teams use their knowledge collectively to identify and analyze opportunities to improve quality (Hackman and Wageman 1995, p. 314). Quality improvement projects usually assume a structured process much like a traditional problem-solving model with problem identification and diagnosis, followed by solution generation and implementation (MacDuffie 1997, March and Simon 1958). A commonly applied problem-solving model in quality management is the PDCA (Plan-Do-Check-Act) cycle (Deming 1986, Shewhart 1939). Taken together, a typical quality improvement process combines a problem-solving model and a collection of statistical and nonstatistical tools.

In a Six Sigma project, these problem-solving elements are integrated into an overall structured method, consisting of specific problem-solving steps with recommended statistical and nonstatistical tools in each step. The Six Sigma method can be defined as "A method that sequences and links improvement tools into an overall approach" (Snee 2000, p. x). Using this structured method is a key component in Six Sigma projects (Pande et al. 2000). A structured method such as Six Sigma can provide a rational and systematic way of capturing and generating knowledge. Like artificial intelligence, it assumes a programmatic approach to learning and creating knowledge (Ericsson and Hastie 1994). From this vantage point, a structured method that is a standardized problem-solving process, can be viewed as a metaroutine that systematizes the problem-solving process (Adler et al. 1999). A structured method, then, represents a cognition-influencing mechanism that leads to learning behaviors and knowledge created in quality improvement teams.

Besides a structured method, quality improvement contains a psychological component. Any sense of threats, such as punishment for failures and fear of judgment, can pose a negative effect on the cognitive processes in people and prevent the organizational members from learning effectively and identifying opportunities for quality improvement (MacDuffie 1997, p. 499). In the organizational learning literature, Edmondson (1999) developed a sociopsychological construct called psychological safety that affected team learning. Psychological safety is a shared belief held by team members that the team is safe for interpersonal risk taking. A psychologically safe environment frees the team members to explore various problems as opportunities for quality improvement. Viewing problems as opportunities is particularly important at the problem-definition stage (MacDuffie 1997). The larger the opportunities defined in early problem definition, the greater the amounts of learning and improvement tend to follow (Levin 2000, p. 631). Psychological safety, thus, represents another mechanism that influences the cognitive processes in teams. We studied these two specific mechanisms—method-driven and psychologically driven—that influence the cognitive processes leading to learning behaviors and knowledge created in quality teams.

Quality management settings are learning oriented; however, ineffective implementation can result in learning failures and antilearning group norms (Hackman and Wageman 1995, p. 333). Causes of such problems include misalignment between the reality and rhetoric (Zbaracki 1998) and resistance among organization members, which generally result in inconsistencies in quality implementation (Boiral 2003). Benner and Tushman (2003) argued that inconsistencies in quality could be caused by the tension between exploitation and exploration. Exploitative learning is variance reducing and exploratory learning is variance seeking (McGrath 2001). Learning in quality settings, however, is generally associated with the reduction of variation (Anderson et al. 1994, p. 485). Variance reduction is most evident in process management techniques—mapping processes, improving processes, and adhering to improved processes—that emphasize efficiency and incremental knowledge (Benner and Tushman 2003). Adhering to a method such as Six Sigma can be viewed as predominantly variance reducing and exploitative. In contrast to variance reducing, variance seeking is associated with creativity and generation of novel ideas and innovative solutions that require divergent thinking and access to a variety of alternatives. Variation fosters creative abrasion between diverse viewpoints producing learning about new ideas for innovations (Leonard-Barton 1995). Although organizational members may use a number of tools in quality improvement, nonroutine and less familiar

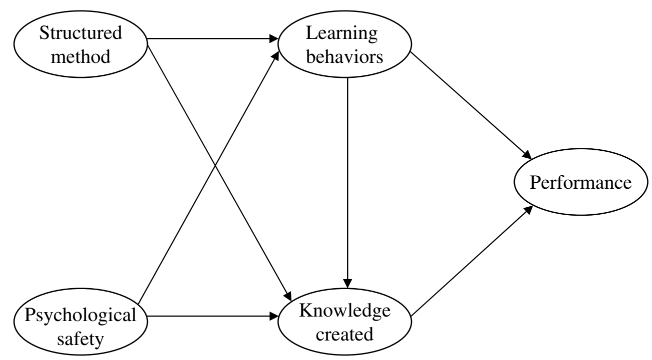
problems are likely to require creativity (Victor et al. 2000, p. 109). When people are put into a psychologically safe environment, creativity and exploration are likely to occur. The difference between variance-seeking (exploratory) and variance-reducing (exploitative) activities, however, can lead to tension in quality settings (Benner and Tushman 2003). To a certain extent, investigating the relative importance of method and psychological mechanisms could offer a better understanding of this potential tension in quality management.

Few empirical studies relate quality and learning. In a case study of quality improvement in three auto assembly plants, MacDuffie (1997) studied the problem-solving process in three specific problem categories—water leaks, paint defects, and functional electrical defects. He found that quality improvement can benefit from rich data that capture multiple perspectives of a problem, from being flexible in categorizing problems, and from organizational structures that facilitate the development of common language to discuss problems. Effective quality improvement depends on how the organization influences its members' cognitive processes and presents problems as learning opportunities. Levin (2000) also studied auto assembly plants, but he focused on car models produced from year to year. He found that the largest amount of learning and improvement happened before introducing the newest car model (disruptive learning). Subsequent introductions represented only minor updates and incremental improvements (the learning curve effect).

Quality improvement depends not only on the production experience, but also on the intensity of offline quality improvement activities and transfer of knowledge over time. In quality improvement projects, Mukherjee et al. (1998) investigated why some projects are more effective than others and found considerable variation along two dimensions of learning in quality improvement projects—conceptual learning (know-why) and operational learning (know-how). Subsequent studies found that projects that acquired both know-why and know-how accelerated the factory's learning rate (Lapré et al. 2000), and that management buy-in and knowledge diversity facilitated knowledge creation and transfer of technological knowledge to other factories (Lapré and Van Wassenhove 2001). Quality-based learning is a function of proactive investment in quality improvement and autonomous learning-by-doing rather than reactive learning from defect reduction (Ittner et al. 2001). Generally, quality-based learning is studied mostly as learning curve models (e.g., Fine 1986, Li and Rajagopalan 1997).

Although prior studies have investigated some forms of learning, there is limited understanding of

Figure 1 **The Theoretical Framework**



the direct impact on knowledge. Studying knowledge and learning behaviors together enables us to investigate their relations and interactions with respect to the method and psychological mechanisms and to understand knowledge as a strategic resource. Instead of investigating how learning in general leads to improvement, this research considers two cognition-influencing mechanisms that can affect learning behaviors and knowledge creation in quality projects. Figure 1 shows the theoretical framework and the details of the constructs. Hypotheses are discussed next.

2.1. Knowledge Created, Learning Behaviors, and Performance

Knowledge can be defined as "a fluid mix of framed experience, values, contextual information, and expert insight that provides a framework for evaluating and incorporating new experience and information" (Davenport and Prusak 1998, p. 5). Scholars have tried to define various types of knowledge—for instance, knowledge of acquaintance versus knowledge-about (James 1950); explicit versus tacit (Nonaka 1994, Polanyi 1966); not observable in use versus observable in use (Winter 1987); individual versus social (Spender 1996); and rich versus schematic (Davenport and Prusak 1998). Besides types and forms of knowledge, the organizational knowledge literature also studies the processes through which knowledge is created (e.g. Nonaka and Takeuchi 1995, Pisano 1994). This branch of literature "steps back from the questions about knowledge types and forms and emphasizes the need to understand the micro-processes by which knowledge is created or acquired" (Vera and Crossan 2003, p. 126). Our research joins this effort to focus on quality improvement projects. As Vera and Crossan (2003, p. 132) argued, learning is the process through which knowledge is created. Accordingly, we characterize learning as a process and knowledge as an outcome.

Specifically, we view knowledge created—new knowledge—as an outcome associated with improved

understanding and capability of the Six Sigma team. This includes the ideas created, solution innovativeness, and enhanced ability to perform future work. In this respect, our approach builds on the organizational knowledge literature (Grant 1996b, Kogut and Zander 1992), where knowledge is viewed as a strategic resource. From a problem-solving perspective, new knowledge is created by identifying a problem and then discovering a useful new solution (Nickerson and Zenger 2004, p. 618). On the other hand, learning is studied predominantly as a process in the organizational learning literature (Vera and Crossan 2003). Organizational learning has been defined as "the process of improving actions through better knowledge and understanding" (Fiol and Lyles 1985, p. 803) and "process of detecting and correcting error" (Argyris 1977, p. 116). Following Edmondson's (1999) work, we conceptualized learning as a behavioral process. Learning behaviors include information seeking and discussions within and outside the team. Learning behaviors through information seeking and discussions facilitate dialogue and interactions that tend to create new knowledge in quality projects. Six Sigma's emphasis on data encourages a team to seek information actively through measurement and discussions. Such learning behaviors can lead to knowledge created.[1]

Learning behaviors through information seeking and discussions not only create knowledge, but also are likely to increase performance directly. Learning behaviors lead to performance because active information seeking and discussions promote performance feedback and early error detection, which are associated with increased organizational effectiveness (Edmondson 1999). For instance, performance is related to seeking information and feedback from outside the team (Ancona and Caldwell 1992) and discussions of failures (Leonard-Barton 1995). Learning behaviors, however, can be time consuming and distract the team from performance. However, for teams facing changes and uncertainty, the risk of wasting time is small relative to potential gains (Edmondson 1999, p. 354). This is a familiar challenge for Six Sigma teams. In a Six Sigma organization, projects are continually formed to address problems due to changes and uncertainty in its organizational processes (Pande et al. 2000). Under such conditions of high task uncertainty, a learning-oriented[2] strategy can be an effective approach to quality improvement (Sitkin et al. 1994). As such, learning behaviors can directly affect performance.

According to the knowledge-based view of firm, knowledge is a strategic resource that the firm uses to develop sustained competitive capability (Kogut and Zander 1992). If knowledge leads to competitive advantage (Grant 1996b), then knowledge created should affect performance. Testing this knowledge-performance link is important to build a better understanding of the source of competitive advantage (Eisenhardt and Santos 2002, p. 158). However, this positive relationship implies that knowledge created is useful and effective, which may not always be the case: "Learning does not always lead to intelligent behaviors" (Levitt and March 1988, p. 335). "Entities can incorrectly learn, and they can correctly learn that which is incorrect" (Huber 1991, p. 89). Learning the wrong things ("wrong" knowledge) can lead to negative performance in quality improvement projects (Lapré et al. 2000). Relevant knowledge, however, can lead to quality improvement (Mukherjee et al. 1998) and waste reduction (Lapré et al. 2000). Effective learning behaviors and relevant knowledge should positively affect performance. As Vera and Crossan (2003, p. 134) argued,

> [I]f learning and knowledge are not relevant to, and consistent with the firm's purpose, they do not guarantee positive results. For knowledge to become a source of competitive advantage, firms need to match their learning/knowledge strategy with their business strategy. When a firm's learning/knowledge strategy matches its business strategy, the impact of knowledge and learning is positive. If this match is not achieved, knowledge and learning may have no impact or even have a negative impact on performance.

This argument suggests that effective learning behaviors and relevant knowledge creation occur when problems are well defined and aligned with the company objectives. We argue that Six Sigma is carefully designed to produce relevant learning behaviors and useful knowledge because of its attention to alignment with company objectives. Six Sigma projects explicitly define problems to have an impact on both the immediate processes and the overall company objectives (Barney 2002). When problems are defined in alignment with the company strategy, Six Sigma teams are likely to generate effective learning behaviors, which in turn create relevant knowledge that positively affects performance.

Taken together, for a learning- and knowledge-based quality project such as Six Sigma, learning behaviors not only should directly affect performance, but also should indirectly affect performance through knowledge created. In other words, the learning- and knowledge-based argument suggests that the effects

[1] Note that learning behaviors influence knowledge created because our construct of knowledge created refers to *newly* created knowledge, as captured by our survey items. However, we do recognize that previously held knowledge, which is not the focus of our study, may influence learning behaviors.

[2] Sitkin et al. (1994) developed a contingency framework in quality that recommends a learning-oriented strategy for high task uncertainty and a quality-control strategy for low task uncertainty.

of learning behaviors on knowledge created, learning behaviors on performance, and knowledge created on performance should be simultaneously positive.

Hypothesis 1 (H1). *Knowledge created partially mediates the relationship between learning behaviors and performance.*

2.2. Structured Method

In a quality improvement project, the team's problem-solving effort can rely heavily on the use of a structured method. A structured method provides a systematic and rational way to solve the problem. By adhering to a systematic process with a logical sequence of steps, the structured method can make the search for solutions more efficient and effective. In Six Sigma projects, the teams use a structured problem-solving method called DMAIC (Define, Measure, Analyze, Improve, Control) (Harry and Schroeder 2000, Pande et al. 2000). This method is patterned after the PDCA cycle (Deming 1986, Shewhart 1939), which also can be viewed as a knowledge-creating process (Garvin 1993, Lim et al. 1999).

Within the framework of DMAIC, the Six Sigma method is heavily integrated with various quality tools like FMEA (Failure Mode and Effects Analysis), cause-and-effect charts, and statistical control charts (Breyfogle 1999, Pande et al. 2000). For the most part, these tools are not new, but the rigorous integration of the tools into each step of the DMAIC could be something new: "What Motorola created was an effective packaging of problem-solving and data analysis tools in a problem-solving process" (Sanders and Hild 2000, p. 303). The integrated Six Sigma method offers a road map to quality improvement with recommended problem-solving steps and tools. If the Six Sigma method is effectively integrated and structured, then adherence to the Six Sigma method can influence learning behaviors and knowledge created in Six Sigma projects.

Theoretically, adherence to a structured method resembles that of a metaroutine. A senior executive from our research site told us that Six Sigma is "a process for changing other processes." A metaroutine can be developed for changing existing routines and inventing new ones (Grant 1996a, Nelson and Winter 1982), which is consistent with how Winter referred to quality management as a "quest for improvement in organizational routines" (1994, p. 93). Such a formal process or sequence of steps can be used to respond efficiently to problems and build organizational knowledge (Feldman 2000, Schulz 1998). A metaroutine can maintain both efficiency and flexibility in problem solving by systematizing the learning behaviors and knowledge creation (Adler et al. 1999, p. 45). In a structured method, the sequence of steps increases the likelihood that a good solution will be discovered during the problem-solving process (Newell et al. 1958, p. 161). Clearly, adherence to a structured method influences how information is gathered and processed (Hackman and Wageman 1995), and thus should directly affect the learning behaviors.

Hypothesis 2A (H2A). *Adherence to a structured method positively influences learning behaviors.*

Learning in quality requires generating new information about the process, which "must be interpreted, understood, and verified" (Anderson et al. 1994, p. 485). Information that "must be interpreted, understood, and verified" represents information infused with meaning and semantics, which is most relevant to knowledge (Nonaka 1994, p. 16). By offering a programmatic discovery of solutions, adherence to a structured method influences the thinking processes of the team and thus should directly affect knowledge creation. For instance, in a Six Sigma project, knowledge can be generated by mapping the processes and discovering the ineffective and/or redundant procedures.

Hypothesis 2B (H2B). *Adherence to a structured method positively influences knowledge created.*

2.3. Psychological Safety

Quality improvement also contains a psychological component. The collection of data in quality improvement projects can be used for accountability and not for actual problem analysis or solution generation. In particular, individuals under threat are unlikely to try new ideas or processes. Intimidation can be a barrier to implementing a quality initiative in an organization, resulting in an indifferent attitude toward quality (Deming 1986, Ryan and Oestreich 1998, Zbaracki 1998). Problems are viewed negatively when individuals or departments believe they will be penalized if they are associated with a problem. Such a negative attitude leads to general avoidance of issues and problems, which negatively influences learning behaviors in quality improvement (MacDuffie 1997). Conversely, a sense of "safety" can cause organization members to view a problem positively and motivate them to improve the quality process. From the work team literature, Edmondson (1999, p. 354) developed a psychological safety construct that attempts to capture the climate of interpersonal trust and mutual respect in teams. She defined psychological safety as a shared belief that the team is safe for interpersonal risk taking. This construct builds on the concept of trust. Trust is a belief that the "results of somebody's intended action will be appropriate from our point of view" (Misztal 1996, pp. 9–10). Trust results in one's willingness to be vulnerable to others because of an expectation that others will perform actions favorable

to one's interests (Mayer et al. 1995). In situations with high levels of trust, people are more willing to take risks (Ring and Van de Ven 1992) because they feel safe to do so. Team members who trust each other tend to feel psychologically safe to discuss problems and issues openly without feeling that they are being judged. Psychological safety should facilitate learning behaviors because "it alleviates excessive concern about others' reactions to actions that have the potential for embarrassment or threat" (Edmondson 1999, p. 355).

Hypothesis 3A (H3A). *Psychological safety positively influences learning behaviors.*

Problems in quality improvement can be framed negatively as liabilities or threats or positively as opportunities. Any sense of threat needs to be eliminated before individuals can identify opportunities in organizational events (Jackson and Dutton 1988). Threats can hinder individuals from "seeing" opportunities and exploring various alternatives. As MacDuffie argued, "the organizational context must... motivate individuals to frame issues as opportunities" (1997, p. 499). When a problem is positively framed, exploration of opportunities for improvement can follow. Identifying opportunities for improvement is exploratory in nature, which likely generates innovative solutions (March 1991).

The shared belief of psychological safety influences the way a team frames the problem and enables individuals to identify and freely explore opportunities in quality improvement projects. Framing problems as opportunities, not threats, explains how psychological safety can directly influence knowledge creation. Opportunity recognition generates new knowledge, as Friedlander (1983, p. 194) argued: "Learning may result in new and significant insights and awareness that dictate no behavioral change" (quoted in Huber 1991, p. 89). These "new and significant insights" can be characterized as knowledge created. The organizational knowledge literature notes that "knowledge is mainly cognitive, including facts and the skills we possess" (Vera and Crossan 2003, p. 126). Besides learning behaviors, psychological safety can lead to cognitive change (i.e., knowledge created). Perceptions of freedom and autonomy encourage creativity (Amabile 1996); thus, a psychologically safe environment tends to be associated with increased creativity, leading to knowledge creation. Conversely, when members sense they are under threats, the team's ability to recognize opportunities for improvement (i.e., knowledge being created) diminishes. In this respect, psychological safety is likely to affect knowledge creation because it influences the cognitive ability of a team to generate insights and identify opportunities to improve in a Six Sigma project.

Hypothesis 3B (H3B). *Psychological safety positively influences knowledge created.*

3. Methodology

Our primary source of data for this study comes from a Six Sigma manufacturing firm, which we will refer to as MFG. MFG is a Fortune 500 company with more than 60,000 employees worldwide. It is a leading manufacturer of computer components and has annual revenue of more than $6 billion. It has been using Six Sigma for three years and is very advanced in its application. MFG has about 200 full-time Black Belt specialists and has completed more than 1,500 Six Sigma projects. Black Belts are highly trained full-time specialists in process improvement who receive more than four weeks of training and hands-on project improvement experience. MFG has documented savings of more than $400 million from its Six Sigma efforts. MFG is also training most of its employees in Six Sigma basics. These individuals, called Green Belts, receive two weeks of training.

At MFG, for each Six Sigma project, teams are formed of employees who have substantial knowledge about the process or product to be improved. They serve on a part-time basis and often have Green Belt training. A full-time Black Belt specialist leads each team. The Black Belt usually reports to the sponsor of the team, called a Champion, who is from senior management and is trained in Six Sigma basics. The Champion provides a holistic view of the organization, helps establish project buy-in, and ensures the availability of resources to the team. Most projects have, on average, targeted savings of $175,000, but this savings target does not necessarily apply to all projects. Some projects may have zero financial savings, but generate other important strategic benefits that are difficult to quantify in financial terms. MFG uses the DMAIC method integrated with both statistical and nonstatistical tools.

3.1. Procedure

Hypotheses developed in this study were tested at the project level in MFG. Testing the theory in a single firm allowed for controls in confounding factors such as variation in products, services, markets, customers, production technology, and corporate culture. On the other hand, different teams within an organization can experience quite different work environments (Sackmann 1992), which allows sufficient sample variation for the theory to be tested at the project level. In particular, despite the emphasis of following the Six Sigma method, we expected variation in the degree of adherence to Six Sigma method in different projects in MFG because the rhetoric and reality of applying the quality method can be quite different (Zbaracki 1998). Variations in the degree of

applying quality tools in projects were also found in other studies in a single firm (e.g., Mukherjee et al. 1998).

We developed a questionnaire to collect data from a sample of MFG's 1,500 completed Six Sigma projects. The most recently completed projects by each Black Belt were selected to minimize the measurement error due to the recency effect. Because the Black Belts came from different business units in MFG, the projects we selected were fairly random and representative of all completed projects in MFG at the time of survey. The Black Belt and team members from each selected project were invited to participate in the survey. Using multiple informants reduced the common method bias and increased validity compared with a single-informant survey design.

The questionnaire was divided into three parts. Black Belts answered the first part, which had questions about performance and knowledge created. Team members answered either the second part, about psychological safety and knowledge created, or the third part, about learning behaviors, the structured method, and performance. Separating theoretical constructs into different parts of the survey reduced the potential common method bias because different people answered the dependent and independent variables. This survey design also reduced the number of questions per survey, which tended to increase the response rate. The survey was Web-based. Confirmatory factor analysis showed that the survey was not hampered by common method variance.

LISREL 8 (Jöreskog and Sörbom 1996) is the estimation technique we used to test the structural equation model constructed from the hypotheses. The LISREL technique has an advantage over standard regression analysis because it explicitly considers the measurement errors associated with indicators (survey items) and simultaneously estimates a system of structural equations. However, the analysis of structural equation modeling can be unstable when the sample size is small. For instance, the analysis might not converge or reach a solution (finding unique parameter values) after numerous iterations. Researchers in structural equation modeling, therefore, commonly recommend a minimum sample size of 100 to 150 (Anderson and Gerbing 1988). Thus, we designed our survey with the aim of gathering responses for a sample size of 150 projects or more.

3.2. Data Collection

Personalized e-mail invitations to participate in the survey were sent by MFG's vice president and the executive director for Six Sigma to 1,233 team members and Black Belts involved with 324 projects. Each personalized e-mail had a customized link that brought the respondent directly to the survey for a specific project. Responses collected through the Web were stored in a protected Microsoft Access database. Follow-up reminders and thank-you e-mails were sent every week for three weeks until we had a satisfactory level of response and concluded the data collection. Some 951 people took the survey, representing a 77% response rate. At the project level, we collected data from 206 projects, which represented a 63.5% response rate. Data for each project was based on responses from the Black Belt and at least two team members.

Although we had multiple informants for all projects, not all theoretical constructs had multiple responses. Two constructs—knowledge created and performance—had multiple responses from the Black Belt and at least one team member for all projects, while other constructs had multiple responses from only a third of the projects. We assessed the inter-rater reliability (IRR) (James et al. 1984) and deleted 18 projects[3] with inconsistent responses ($\text{IRR} \le 0, >1$) and low agreement ($\text{IRR} < 0.10$) to better capture the constructs at the group level. The remaining 188 projects had an average IRR greater than 0.87 for all constructs with multiple responses. Using a one-way ANOVA, we also compared within-project variance and between-project variance for the knowledge created and performance constructs. F statistics were significant, which indicated significant between-project variances. We did not conduct the same test for other constructs because they had multiple responses for only a third of the projects. Although we did not have multiple responses for all constructs, the results of the two tests showed sufficient evidence that the data were consistent at the project level and appropriate to aggregate the item scores for constructs with multiple responses in each project. We aggregated multiple responses by taking averages for the respective item scores in each project to arrive at the final sample of 188 projects.

3.3. Measures

All multi-item measures in this study had a seven-point Likert scale. The theory developed for the constructs helped define the domains of each measure. We used validated measures from extant research whenever possible to operationalize the constructs in the theoretical framework. Most measures were adapted to make them more suitable for this research setting, and new measures were developed as needed.

The survey was pretested at MFG by six Black Belts and eight team members. Five university researchers knowledgeable about Six Sigma also pretested the

[3] We also checked that these 18 deleted projects were not systematically different from the retained projects.

instrument. The survey pilot test assessed three main characteristics of the survey: clarity (Is each question clear and easy to answer?), content (Does each question make sense and is it appropriate?), and the average time taken to answer the questionnaire.

Reliabilities of the measurement scales exceeded the recommended 0.7 (Nunnally 1978), with the exception of the learning behaviors scale; it had an alpha of 0.62, which was acceptable for new and revised scales (Robinson et al. 1991). The appendix contains a list of all items in the survey.

Psychological Safety (Cronbach $\alpha = 0.74$). The scale measured the climate of the project team characterized by members' feeling safe and comfortable with each other. The three items in the scale were adapted from Edmondson's team psychological safety scale (1999).

Structured Method (Cronbach $\alpha = 0.74$). This scale measured the adherence of the problem-solving steps in the Six Sigma method (DMAIC). We developed three new items for this scale.

Learning Behaviors (Cronbach $\alpha = 0.62$). This scale measured the interactions of the team members characterized by discussions, asking questions, and seeking information. We adapted four items from Edmondson's scale of team learning behaviors (1999).

Performance (Cronbach $\alpha = 0.91$). This scale has four items that measured the degree of successful project outcome in terms of meeting customers' expectations and achieving results, goals, and impact. We developed this scale to measure the improvement results from Six Sigma projects.

Knowledge Created (Cronbach $\alpha = 0.78$). This construct measured the degree of solution uniqueness, idea generation, and improved understanding and capability of the team members after the project was completed. It is a three-item scale with two new items and the third item adapted from Roth and Jackson's knowledge scale (1995).

4. Analysis and Results

Descriptive statistics for all items are shown in Table 1. The means and standard deviations show adequate variation of the indicator variables. The data also show some degree of nonnormality due to a moderate level of kurtosis for some items. Although structural equation modeling using the maximum likelihood technique is fairly robust, recent literature indicates that maximum likelihood estimation is sensitive to nonnormality (Boomsma and Hoogland 2001). Nonnormality could lead to inflated chi-square statistics and underestimated standard errors of parameter estimates (West et al. 1995). Underestimated standard errors could result in significant paths and correlations between factors, even though they do not exist in the population. To deal with these potential problems, we transformed all indicator variables using PRELIS's normal scores procedure (du Toit and du Toit 2001, p. 143). Transformed variables indicate satisfactory univariate normalities with values of skewness and kurtosis within ±0.5 (see Table 1). Mardia's (1970) normalized coefficients for multivariate skewness = 6.367 and multivariate

Table 1 Descriptive Statistics of Original and Transformed Variables

	Original				Transformed			
Item	Mean	Std. dev.	Skewness	Kurtosis	Mean	Std. dev.	Skewness	Kurtosis
KD1	5.87	0.648	−0.964	2.501	5.87	0.648	−0.044	−0.124
KD2	5.36	0.896	−0.796	0.712	5.36	0.896	−0.025	−0.040
KD3	5.73	0.673	−1.385	4.086	5.72	0.673	−0.050	−0.031
PF1	5.45	0.886	−1.173	3.376	5.45	0.886	−0.033	−0.133
PF2	5.76	1.005	−1.539	3.271	5.76	1.005	−0.101	−0.261
PF3	5.44	1.030	−0.812	0.806	5.43	1.029	−0.056	−0.222
PF4	5.96	0.761	−1.667	4.762	5.96	0.761	−0.082	−0.210
DL1	5.13	1.077	−0.729	0.192	5.13	1.076	−0.133	−0.155
DL2	5.39	0.852	−0.826	1.009	5.39	0.852	−0.135	0.013
DL3	5.51	0.872	−0.663	0.654	5.51	0.871	−0.080	−0.122
DL4	5.00	1.182	−0.548	−0.114	4.99	1.181	−0.065	−0.240
ST1	5.23	1.030	−0.630	0.092	5.23	1.029	−0.105	−0.111
ST2	5.32	1.114	−0.689	0.103	5.32	1.114	−0.093	−0.204
ST3	5.10	1.008	−0.655	0.149	5.10	1.008	−0.146	−0.139
PS1	5.86	0.973	−1.159	1.954	5.86	0.972	−0.253	−0.419
PS2	5.55	0.931	−1.503	3.914	5.55	0.931	−0.184	0.058
PS3	5.46	1.259	−0.863	0.067	5.46	1.258	−0.153	−0.422

Note. Please see the appendix for detailed descriptions of the item variables.

Table 2 Parameter Estimates

Correlations/path coefficients (standard errors)	Theoretical model	Theoretical model with transformed data
Learning behaviors and structured method	0.59 (0.14)***	0.60 (0.13)***
Learning behaviors and psychological safety	0.059 (0.092)	0.076 (0.092)
Performance and learning behaviors	0.34 (0.11)***	0.40 (0.11)***
Performance and knowledge created	0.44 (0.090)***	0.36 (0.094)***
Knowledge created and learning behaviors	0.38 (0.15)**	0.32 (0.14)*
Knowledge created and structured method	−0.074 (0.12)	−0.026 (0.13)
Knowledge created and psychological safety	0.46 (0.091)***	0.46 (0.097)***
Psychological safety and structured method	−0.06 (0.09)	−0.05 (0.09)

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

kurtosis = 6.182, which indicate small multivariate nonnormality, remain, but the transformed data were sufficient for our purpose. We then analyzed our model using both transformed and original data and found that the model fit indices, standard errors, and parameter estimates remained stable across both data sets. None of the significant paths in the analysis of original data became insignificant in the transformed data. These results show that the maximum likelihood estimation is robust against moderate nonnormality for our data set. We report results of the model analysis using both transformed and original data in Table 2. Because the results from both data sets are consistent, we will discuss the analysis based on the original data in the following sections.

4.1. Modeling Analysis

We conducted our analysis of the structural equation modeling in two stages (Anderson and Gerbing 1988). In the first stage, we assessed the convergent and discriminant validities of all constructs by building a measurement model estimated through maximum likelihood confirmatory factor analysis (CFA). In a CFA, all possible paths between constructs are estimated by bidirectional correlations. Factor loadings of the measurement model ranged from 0.45 to 0.84. All loadings were positive and statistically significant, which represented acceptable convergent validity for all constructs (Bagozzi and Yi 1991). We conducted the test of discriminant validity by constraining between-construct correlations to 1.0 one at a time for correlations greater than 0.3 and recorded the changes in χ^2 statistic; all $\Delta\chi^2$ (on 1 d.f.) were highly significant at the 0.001 level. We also computed the confidence intervals (± two standard errors) for all correlation estimates and found that none included 1.0. Results of the two tests suggest adequate discriminant validity for all constructs (Anderson and Gerbing 1988).

In assessing the overall fit of the model, we looked at the χ^2 statistics, comparative fit index (CFI), non-normed fit index (NNFI), root mean square error of approximation (RMSEA), and changes in the residual distribution recommended by the literature (Hu and Bentler 1999). The results of the CFA provide evidence of a good fit: All fit indices exceed 0.95, RMSEA is less than 0.05, the χ^2 statistic is nonsignificant at the 0.05 level, and none of the 136 normalized residuals is beyond ±3 (one exceeds 2.50 with a value of 2.59). We therefore proceeded to evaluate the hypotheses by testing the theoretical model (see Figure 1).

Results of the theoretical model analysis show a nonsignificant χ^2 statistic of 143.32 ($p = 0.021$) at the 0.01 level. Analysis of transformed data shows an even stronger result of nonsignificant χ^2 statistics at the 0.05 level. We also used a robust maximum likelihood technique in LISREL and found the Satorra-Bentler scaled χ^2 to be nonsignificant ($p = 0.38$). This statistic corrects for nonnormality in the data (Satorra and Bentler 1994).

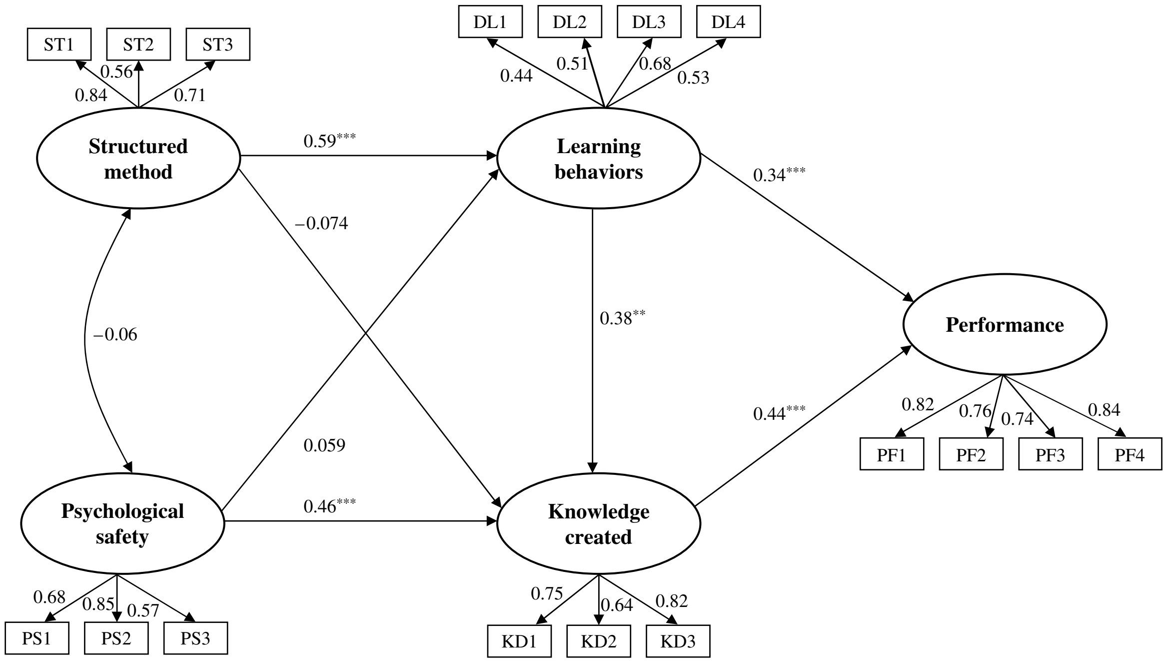
Fit indices of the theoretical model indicate a good fit with CFI = 0.98, NNFI = 0.97, RMSEA = 0.039, and none of the 136 normalized residuals is beyond three standard deviations (three are beyond ±2.50). Overall, these results indicate a good fit of the theoretical model with the data. Path estimates in the theoretical model are provided in Table 2.

H1 is supported: The positive relationship between learning behaviors and knowledge created ($\beta = 0.38$, $p < 0.01$) and the positive effects of learning behaviors and knowledge created on performance are simultaneously supported ($\beta = 0.34$, $p < 0.001$; $\beta = 0.44$, $p < 0.001$). We found that the structured method influences learning behaviors (H2A supported; $\gamma = 0.59$, $p < 0.001$) but shows no direct association with knowledge created (i.e., H2B not supported). The data also provide no support for the positive relationship between psychological safety and learning behaviors (H3A not supported), but the positive relationship between psychological safety and knowledge created is supported (Hypothesis 3B supported: $\gamma = 0.46$, $p < 0.001$). These results are summarized in Figure 2.

4.2. Additional Analysis

Given that psychological safety and the structured method were uncorrelated (−0.06), we wanted to check whether they interacted with one another instead. Therefore, we performed an additional analysis by estimating a Kenny-Judd interaction model (1984) via the deviation score approach in LISREL (Algina and Moulder 2001). Specifically, we first centered the indicator variables for the structured method and

Figure 2 Theoretical Model Analysis



Note. Model statistics: $\chi^2 = 143.32$ ($p = 0.021$), d.f. = 111, $n = 188$, RMSEA = 0.039, NNFI = 0.97, CFI = 0.98, $^{***}p < 0.001$, and $^{**}p < 0.01$.

psychological safety, and then computed the cross products of the two sets of indicator variables (three items by three items) to represent the interaction between the structured method and psychological safety. This exercise produced nine derived indicator variables representing the interaction between the structured method and psychological safety. In the structural model, we tested the interaction by putting in an additional latent construct representing the interaction with arrows pointing to learning behaviors and knowledge created. The rest of the model remained the same as the original. Analysis of the interaction model showed a poor model fit (e.g., NNFI = 0.76, RMSEA = 0.09). The two paths from the interaction latent factor to learning behaviors and knowledge created were both nonsignificant, thus showing no evidence of interaction between the structured method and psychological safety. Modeling interaction effects using structural modeling equation, however, is an emerging application and has some problems in estimating standard errors for path coefficients (Schumacker 2002). In particular, the standard errors typically are underestimated (Algina and Moulder 2001). Despite this problem, our results remain sound because the interaction path coefficients are already nonsignificant even with the potentially underestimated standard errors. Therefore, our results suggest that the structured method and psychological safety are two different sources of knowledge creation that are distinct and noninteracting. The effects of the structured method and psychological safety are complementary.

5. Discussion and Conclusions

This study investigates knowledge creation in quality improvement projects from two sources—psychological safety and structured method. Despite their cognitive association, they are distinct and noninteracting. In an environment increasingly driven by knowledge, an organization can manage knowledge creation by considering these two distinct sources—structured method and psychological safety, which can be managed independently. Due to this independence property, the two mechanisms can be handled flexibly. A manager can provide an environment with both mechanisms present, but may choose to emphasize one mechanism over the other. For instance, Six Sigma projects with highly structured tasks, typically those for improving manufacturing or service processes, could focus mainly on using the method because the problems are relatively structured and stable. Conversely, Six Sigma projects that are highly unstructured, such as those for developing a new product or service, could focus on creating a trusting and psychologically safe environment where team members can freely explore opportunities in problems that are ill-defined and dynamic. This implication could apply to other knowledge-intensive projects and activities such as decision analysis, technical support, and software development.

In addition to the independence property, the structured method and psychological safety have different effects on the learning behaviors and knowledge creation. A structured method has a direct influence on learning behaviors and an indirect one on

knowledge created. It also indirectly influences performance. While some research found TQM tools and techniques to have no direct effect on performance (Powell 1995, Samson and Terziovski 1999), others found that for innovation-oriented organizations process management techniques could have a second-order effect on performance (Ittner and Larcker 1997). This suggests that the impact of tools and techniques on performance is probably indirect. Our research findings support such an indirect relationship using a knowledge-based argument. In particular, adhering to a method can modify the learning behaviors in quality improvement, which subsequently have an impact on knowledge creation and performance. The choice of a method and the degree of adherence can shape the learning path of the firm and affect how a firm innovates and creates knowledge.

Psychological safety influences knowledge created, but not learning behaviors. The nonsignificant relationship between psychological safety on learning behaviors differs from the significant relationship found in Edmondson's (1999) study. The nature of this difference could be empirical because of how we adapted her scales to our research context, but it also has theoretical implications. Our modified learning behaviors scale captures interactions characterized by information seeking and discussions. We argue that such activities tend to be exploitative in nature, given the association of this modified scale with the structured method, which emphasizes efficiency and incremental improvements. However, the modified psychological safety scale captures the atmosphere of freedom to explore, characterized by openness, mutual respect, and acceptance. This psychologically safe atmosphere likely encourages risk taking and exploration, which tends to create knowledge characterized by innovative solutions, improved team ability, and abundance of ideas.

To the extent that the structured method is directly associated with learning behaviors and psychological safety with knowledge created, the structured method is likely an exploitation mechanism and psychological safety an exploration mechanism. The method mechanism can be seen as a structured approach for variance reducing or exploitation, and the psychological mechanism as an unstructured approach for variance seeking or exploration. Together with the independence property of the structured method and psychological safety, this implication suggests that exploitation and exploration could occur concurrently without conflicting. Although exploration and exploitation can be incongruent (Levinthal and March 1993), Benner and Tushman (2003) argued that organizations using process management practices such as TQM and Six Sigma can become ambidextrous and simultaneously manage exploration and exploitation. Our findings provide evidence of this possibility of simultaneously managing exploitation and exploration in Six Sigma projects.

In the knowledge-based view of firm, an underlying assumption is that knowledge leads to performance (Eisenhardt and Santos 2002). Our study investigated this assumption at the project level and found that knowledge created not only influences performance directly, but also partially mediates the relationship between learning behaviors and performance. Learning behaviors influence performance and knowledge created and mediate the relationship between the structured method and knowledge created in Six Sigma projects. These direct and indirect roles of knowledge created and learning behaviors on performance are important findings for future research in explaining variations in project and firm performance, thus adding to other studies about knowledge management and performance (e.g. Edmondson et al. 2003, Fedor et al. 2003). This research also shows that investigating knowledge created and learning behaviors as separate constructs can be a useful endeavor. In addition, because we argue that a Six Sigma project is carefully defined to produce relevant learning behaviors and useful knowledge due to its attention to alignment with company objectives, the positive finding of H1 also indicates evidence of support, albeit indirectly, for such attention to alignment in Six Sigma projects.

Finally, our study is limited by data collected in a single firm. Although testing the theory in a single firm allows for controls in confounding factors, such as variations in products and corporate culture, testing in a single organization lacks external generalizability. Further replication studies in other organizations are needed before the theory is fully tested. In addition, longitudinal and experimental studies could ascertain the causal relationships. Our results are also limited by our focus on completed projects. We do not have data on failed projects, but investigating why some Six Sigma projects failed could be an interesting extension to this research. Additionally, our study investigates psychological safety as one type of psychological mechanism. Future research could study other psychological effects on learning and knowledge creation.

In conclusion, our paper makes important theoretical and empirical contributions to the literature about learning and knowledge creation using a quality improvement approach such as Six Sigma. Our work contributes in two ways. The first is a better understanding of the relative importance of method and psychological mechanisms on learning behaviors and knowledge creation in quality projects, such as the Six Sigma projects. According to the quality and knowledge management literature, such method and

psychological aspects in linking quality and knowledge creation have not been empirically investigated. Although one might expect possible tensions between the two approaches, we found both to be appealing and their effects on knowledge creation to be complementary. Thus, the choice of a method and the degree of its adherence can affect how a firm innovates and creates knowledge.

The second contribution lies in empirically testing the mediating roles of knowledge created and learning behaviors on performance. Our findings show that learning behaviors affect performance directly and indirectly through knowledge created, thus making both learning behaviors and knowledge important in explaining performance for future research. As quality and learning are inherently related (Senge 1999), we argue that an effective quality program should be learning- and knowledge-based, integrating both learning and knowledge creation. It is our hope that by linking quality, learning, and knowledge creation, this paper contributes to a better understanding of quality, organizational learning, and knowledge management.

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Appendix

Survey Items

All responses range from 1-strongly disagree to 7-strongly agree.

Performance
- PF1 We met or exceeded customers' expectations in this project.
- PF2 This team did not meet the project goals. (reversed)
- PF3 The cost savings or strategic impact of the project were significant.
- PF4 The project was effective in improving the process or product.

Knowledge created
- KD1 Doing this project enhanced the team's abilities and knowledge to perform future work.
- KD2 Solutions found in doing this project were clearly unique and innovative to the company.
- KD3 This team generated many ideas while doing the project.

Learning behaviors
- DL1 The team members went out and got all the information they possibly could from others, such as customers or other parts of the organization.
- DL2 The team's discussions often led to new information.
- DL3 Members of this team often spoke up to test assumptions about issues under discussion.
- DL4 The team often invited people from outside the team to present information and had discussions with them.

Psychological safety
- PS1 Members of this team were able to discuss problems and tough issues openly.
- PS2 Members of this team accepted each other's differences.
- PS3 No one on this team deliberately acted in a way that undermined our efforts.

Structured method
- ST1 The project strictly followed the sequence of DMAIC steps.
- ST2 The team felt that following the DMAIC steps was not important. (reversed)
- ST3 Each step in DMAIC was faithfully completed.

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